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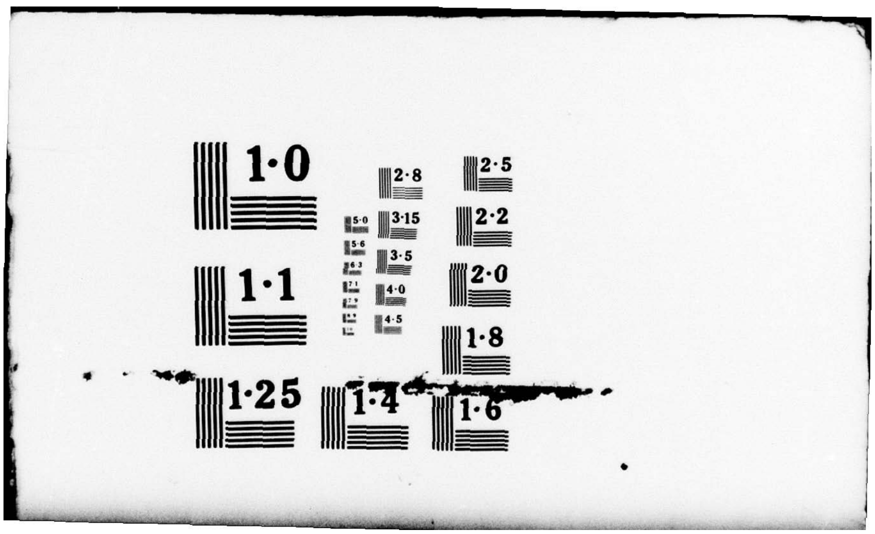
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THE HYPERSONIC FLOWING AROUND OF THIN BLUNTED BODIES

by

M. D. Ladyzhenskiy

FOREIGN TECHNOLOGY DIVISION

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EDITED TRANSLATION

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THE HYPERSONIC FLOWING AROUND OF THIN BLUNTED BODIES

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

THE HYPERSONIC FLOWING AROUND OF THIN BLUNTED BODIES

M.D. Ladyzhenskiy (Moscow)

The hypersonic flowing around of a thin blunted body of an arbitrary cross section is examined. Under the assumption that the whole mass of the gas is concentrated in an infinitely thin layer behind the shock wave [1, 2], the following assertion is correct: the force of resistance acting on the body and the shape of the shock wave depend with the fixed parameters of the advancing flow on the magnitude of resistance of the blunting and the law of the change in direction along the flow of the area of the cross section of the body.

The geometric dimensions of the examined body satisfy the relation $d/l \ll 1$, where d is the maximum dimension of the cross section, and l is the length of the body. Furthermore, condition (3) is fulfilled, the necessity of which follows from the subsequent. From this condition, in particular, it follows that the resistance of the body with respect to the order of magnitudes in any case must not exceed the resistance of the blunting.

The problem of the streamline flow is reduced to the equivalent problem on the nonstationary motion of gas displaced by the piston, whereupon the action of small blunting is replaced by the effect of the instantaneous energy release in the tip of the body O (there occurs a cylindrical explosion, at which the energy of the explosion E, referred to a unit of length, is equal to the resistance of the blunting X_0). In the direction of the blunting the gas is acted upon by the concentrated pulse, the

magnitude of which, however, in the equation of the pulse can be neglected [1, 2].

When t is close to zero (t - the time which is introduced by the relation x = ut, where x is the coordinate read off in the direction of the flow from point O, u - the rate of the undisturbed flow), there appears a flow caused by the powerful point explosion, which possesses cylindrical symmetry with respect to point O. Within the accepted assumptions the flow possesses an axial symmetry when t is close to zero at any, even non-axisymmetric, form of blunting and is determined only by the magnitude of drag of the blunting. (Let us note that this would be impossible to confirm if in the equation of the impulses it was impossible to disregard the effect of the concentrated impulse imparted to the gas in the direction of the blunting. In this case the additional assumption about the axisymmetric form of blunting would be required.)

If we assume further that the whole mass of the gas is concentrated in the infinitely thin layer behind the shock wave, the form of the shock wave in the subsequent layer preserves a cylindrical symmetry, which follows from the impulse and energy equations.

Similar to [1, 2], these equations are written (the dot denotes differentiation with respect to t)

$$\frac{1}{2}\rho_1 R^2 \dot{R} = \int_0^t (p - p_1) R\,dt \qquad (1)$$

$$\frac{\pi}{2}\rho_1 R^2 \dot{R}^2 + (\pi R^2 - S)\frac{p}{\varkappa - 1} = E + \frac{\pi p_1 R^2}{\varkappa - 1} + \int_0^t p\dot{S}\,dt \qquad (2)$$

Here R is the radius of the shock wave, p - pressure in the region between the shock wave and body constant at the given moment in the whole region due to the assumption about the concentration of the entire mas of gas in the infinitely thin layer behind the shock wave; p_1 and ρ_1 - pressure and density, repectively, of the undisturbed gas; S - area of cross section of

the body or, in equivalent problem, area of the piston; κ - adiabatic index.

According to equation (2), the single magnitudes determining the form of the body are E and S(t), i.e., we can confirm the following: with the flowing around by hypersonic flow, the parameters of which are fixed, of thin blunted bodies with equal magnitudes of drag of blunting and the identical law of the change in direction along the flow of the cross section, the forces acting on the bodies in the examined approximation are equal to each other (the total drag force X acting on the body is

$$X = X_0 + \int_0^{\tau} pS\,dt$$

where $\tau = l/u$). Furthermore, for such bodies the shock waves have an identical form, being surfaces of rotation.

From the account given above, it follows that for the reduction to a minimum of the drag of the thin blunted body of noncircular cross section, the law of the change in the area of cross section must coincide with the appropriate law for the equivalent blunted body of rotation of the minimal wave drag.

Further, as it is easy to see, the drag force acting on the body is not changed with the presence of the angle of attack (under the condition that the magnitude of the drag of the blunting is not changed, which will be approximately fulfilled with a spherical shape of the blunting), since the presence of the angle of attack leads to the movement of the piston as a rigid whole without a change in its area.

The given discussions are valid with one important limitation: the equivalent piston must remain within the circle of the radius R with the center at point O, which symbollically we write

$$S \subset \pi R^2 \tag{3}$$

i.e., the surface of the piston nowhere touches the surface of the shock wave. More accurately, the minimum distance between the surface of the piston and the shock wave, referred to the radius of the shock wave, exceeds in order of magnitudes $\varepsilon = (\varkappa - 1)/(\varkappa + 1)$ which when $\varkappa \to 1$ leads to the requirement of the absence of the touching between surfaces of the shock wave and piston. As it is easy to see, from this condition it follows, in particular, that the magnitude of the drag of blunting must exceed or, at least, be comparable in order of magnitudes with the drag of the remaining part of the body. In the opposite case, at a certain $x < l$ the effect of the blunting will cease to affect the layer of gas compressed by the shock wave, and when $\varkappa \to 1$ it will be located along the surface of the body, and the discussions will lose force.

When condition (3) is fulfilled, all the conclusions remain correct if within the circle of the radius R not one but several pistons are expanded. Here the i-th piston begins to be expanded at the moment of time $t = \tau_i > 0$ from point O_i not coinciding in general with point O. In equation (2)

$$S = \Sigma S_i$$

The result obtained in the indicated statement is carried over to a similar case of the three-dimensional nonstationary flow: at the fixed initial parameters of the gas, the flow depends on the energy of the point explosion and the law of the change in the total volume displaceable by the piston (or pistons); it is clear in the assumption that the piston remains within the sphere limited by the shock wave.)

The obtained result reminds us of the result of the theory of the thin body [3] with moderate supersonic M numbers, according to which the drag of the thin body depends only on the law of the change in the area of the cross section, and the near-sonic rule of the areas [4], and therefore can be called, by analogy, the hypersonic rule of the areas.

The hypersonic rule of the areas can be combined with the law of similitude for the flowing around of blunted thin bodies [5, 6], as a result of which the flow near the body in the appropriate dimensionless variables will be determined by two dimensionless parameters - the hypersonic parameter of similitude and the parameter which characterizes the blunting,and one dimensionless function which expresses the law of the change in area of the cross section.

It should be noted that the obtained result, being the consequence of the approximate assumptions, up to a certain degree corresponds to the actual position of the objects, when with the hypersonic flowing around of the blunted body near the body an entropy layer with a small density is formed.

It is possible to expect that in the precise formulation the form of the shock wave and the drag of the body are little sensitive to such a change in the form of the body at which the drag of the blunting and the law of the change in the area of the cross section are retained.

In conclusion the author expresses his thanks to A.I. Golubinskiy and V.V. Sy[illegible] for their very useful discussion.

Submitted 17 April 1960

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